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Rice and Sturgeon Lakes Nutrient Budget Study

Sediment Pigment Stratigraphy as Evidence of Long Term Changes in Primary Productivity of Sturgeon and Rice Lakes

R/S Technical Report No. 4, March 1994

Ontario
Ministry of Environment and Energy
Ministry of Natural Resources

Environment Canada Parks Service
Trent-Severn Waterway

Environnement Canada Service des parcs
Voie navigable Trent-Severn

ISBN 0-7778-1129-4

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MARCH 1994

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PIBS 2878

SEDIMENT PIGMENT STRATIGRAPHY AS EVIDENCE OF LONG TERM CHANGES IN PRIMARY PRODUCTIVITY OF STURGEON AND RICE LAKES

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PREFACE

The Kawartha lakes are a large and economically important system of eight large lakes which are located in central Ontario. Sturgeon Lake and Rice Lake are located near the upper and lower ends of the Kawartha Lakes system respectively and both support significant amounts of urban and recreational development. They were chosen for detailed study because of their importance within the system and because both have shown the symptoms associated with excessive nutrient input for several years.

The Rice and Sturgeon Lakes Nutrient Budget Study was initiated to investigate linkages between point and non-point sources of nutrients, water quality, and aquatic life within the lakes and to estimate the impacts of these processes on in-lake water quality.

The study was supervised by the Rice - Sturgeon Lakes Nutrient Budget Technical Committee which had representatives from the Limnology Section (Water Resources Branch) and Central Region of the Ontario Ministry of the Environment and Energy, the Trent Severn Waterway (Environment Canada) and the Kawartha Lakes Fisheries Assessment Unit of the Ontario Ministry of Natural Resources.

This is one of a series of technical reports. These and the summary report (R/S Tech. Rep. No. 13) will provide a technical basis for the management of the Rice Lake and Sturgeon Lake ecosystems and for the use of land and water resources in the Kawartha Lakes region in general. A list of all reports in the R/S Tech. Rep. series is as follows:

1. Hutchinson N.J., B.J. Clark,, J.R. Munro and B.P. Neary 1993. Hydrological data for the watersheds of Rice Lake and Sturgeon Lake.1986 - 1989, 100 pp.

2. Hutchinson N.J., J.R. Munro, B.J. Clark and B.P. Neary. 1993. Water chemistry data for Rice Lake, Sturgeon Lake and their respective catchments. 1986-1989, 169 pp.

3. Hutchinson N.J., B.P. Neary, B.J. Clark and J.R. Munro 1993. Nutrient Budget data for the watersheds of Rice Lake and Sturgeon Lake. 120 pp.

4. Ryback, M. and I. Rybak. 1993. Sediment pigment stratigraphy as evidence of long term changes in primary productivity of Sturgeon and Rice Lakes (Kawartha Lakes). 24 pp.

5. Nicholls, K.H., M.F.P. Michalski and W. Gibson. 1993. Trophic interactions in Rice Lake I: An experimental demonstration of effects on water quality.

6. Limnos Ltd. 1993. Partitioning of phosphorus in *Potamogeton crispus*. 22 pp.

7. Limnos Ltd. 1993. Rice Lake macrophytes: distribution, composition, biomass, tissue nutrient content and ecological significance. 123 pp.

8. Beak Consultants Ltd. 1993. Release of phosphorus from Rice Lake sediments. 31 pp .

9. Limnos Ltd., Michael Michalski Associates and D.J. McQueen. 1993. Trophic interactions in Rice Lake II. Young-of-the-year yellow perch - *Daphnia* interactions, preliminary findings. 101 pp.

10. Badgery, J.E., D.J. McQueen, K.H. Nicholls and P.R.H. Schaap. 1993. Trophic interactions in Rice Lake III: Potential for biomanipulation. 1988 and 1989 .

11. Standke, S. 1993. The zooplankton of Rice Lake and Sturgeon Lakes, 1986-1988, Kawartha Lakes, Ontario .

12. Nicholls, K.H. 1993. The phytoplankton- water quality relationships of the Kawartha Lakes, 1972-1989.

13. Hutchinson, N.J., K.H. Nicholls and S.H. Maude, 1993. Rice and Sturgeon Lake Nutrient Budget Study: Summary and recommendations.

DISCLAIMER

This report was prepared for the Ontario Ministry of Environment and Energy as part of the Rice and Sturgeon Lakes Nutrient Budget Study. The views and ideas expressed in this report are those of the authors and do not necessarily reflect the views and policies of the Ontario Ministry of Environment and Energy. The mention of trade names and products does not constitute endorsement or recommendation of their use.

ABSTRACT

Some aspects of the limnological histories of Rice Lake and Sturgeon Lake were reconstructed through a detailed analysis of fossil pigments. Sediment deposition rates in Rice Lake and Sturgeon Lake increased from about 10 mg/dm^2/year in the early 1900's to about 60 mg/dm^2/year during the 1980's in both lakes. The blue-green algal pigment oscillaxanthin has increased over time in the sediments of both lakes reflecting the apparently increasing dominant role of blue-green algae with nutrient enrichment over time. The stratigraphic sequence of chlorophyll derivatives to total chlorophyll ratios suggests that the proliferation of macrophytes was also an important component of the eutrophication process in both lakes.

RESEARCH REPORT

prepared for

ONTARIO MINISTRY OF THE ENVIRONMENT
(K.H. Nicholls, Aquatic Biological Section)

July, 1987

INTRODUCTION

Many lakes are undergoing accelerated aging (eutrophication) due to man's activities. The resultant problems (prolific weed growth, nuisance algal blooms, deteriorating fisheries, impaired water quality, and sediment infilling) may pose a serious threat to the utilization of these lakes.

The Kawartha Lakes are an important recreational area in Southern Ontario. Two large lakes in the system, Rice and Sturgeon Lakes have been eutrophic for several decades. Nutrient enrichment is influenced directly by discharges of effluent from municipal sewage treatment plants at Peterborough (Rice Lake) and Lindsay (Sturgeon Lake) (Ontario Ministry of the Environment, 1976).

Concern for water quality conditions in Sturgeon Lake began at least as early as 1948 - 1951. At that time several deaths of animals as a result of drinking water contaminated with toxins associated with blue-green algae have been reported. Investigation by the Ontario Ministry of the Environment (1976) revealed that the phytoplankton communities of Sturgeon and Rice Lakes were dominated by the blue-green algae Anabaena spp. Aphanizomenon spp. and Microcystsis spp. At present, blooms of these algae are still a common occurrence in the Kawartha Lake System.

As a result, this paleolimnological study was initiated to address specific questions about the trophic development of Rice and Sturgeon Lakes: (1) could the record of changes in blue-green algal populations be interpreted from pigments preserved in lake sediments, (2) had productivity changed recently, (3) had the hypolimnetic regime been different in the past (4) could evidence of the past changes in water quality be dated using the Pb-210 radionuclide method?

In this study some aspects of the limnological history of Rice and Sturgeon lakes are reconstructed through a detailed fossil pigments analysis. The development of blue-green algae was traced through myxoxanthophyll, and abundance of Oscillatoria was estimated using oscillaxanthin, a pigment unique to the Oscillatoriacea (e.g. Giriffiths at al. 1968; Zullig, 1961, 1985; Rybak, 1986, Rybak & Dickman, 1987). The Pb-210 radionuclide technique was attempted for reconstruction of the sediment chronology.

MATERIALS AND METHODS

The research was carried out on Rice and Sturgeon Lakes, Ontario. The sediment coring was conducted at Rice Lake in July 1986 (Fig. 1) and at Sturgeon Lake (Fig. 2) in October 1986. Sediment was extruded upward from the core tube and sectioned into 1.0 cm increments.

Pigments were extracted from a subsample of 1 cc of sediment in aqueous 90 % acetone. Chlorophyll derivatives were measured at 665 nm and expressed as absorbance per gram of organic matter, where one unit is equal to an absorbance of 1.0 in a 10 cm cell when dissolved in 100 ml solvent (standard pigment unit). Carotenoids were analysed by solvent sorption with the saponification method (Rybak & Rybak, 1985 b), determined by measuring absorbance at 448 nm and expressed in the same unit as for chlorophylls.

Oscillaxanthin and myxoxanthophyll were determined by solvent sorption. Calculation of these pigments was based on the trichromatic method which mathematicaly separates and quantifies oscillaxanthin, myxoxanthophyll and the contaminating phorbins (Swain, 1985). The concentration of each pigment in the sediment was expressed as ug pigment per gram of organic matter.

For each sediment sample, dry weight and organic content were determined from weight loss on ignition.

RESULTS

Dating and sediment accumulation

Unsupported Pb-210 activity was determined at thirty three levels to a depth of 33 cm in two cores from Sturgeon Lake and at thirty levels to a depth of 30 cm in the core from Rice Lake. In two cores from Sturgeon Lake, Pb-210 activity plotted against sediment depth exhibited an exponential decline below 24 - 25 cm depth (Fig. 3, 4), whereas in the upper sediments the lead activity was nearly constant. Constant Pb-210 activity was also recorded in the core from Rice Lake (Fig. 5).

Sediment age was calculated using the model of Appleby & Oldfield (1978) which assumes a constant rate of supply (c.r.s.) of unsupported Pb-210 to the sediments. This model has been already successfully applied in the Kawartha Lakes by Evans (1984) during her study on Lower Chemung Lake.

In Sturgeon and Rice Lakes, sediment accumulation rates have accelerated over time, diluting Pb-210 concentration apace with rate of lead decay. This is illustrated in Figure 6, where c.r.s. calculations of sediment accumulation rate are plotted.

In Rice Lake, changes in sediment accumulation rate begins in the 1930's, but the most drastic increase started ca. 1954-1955. During the period of ca. 1954 - 1986 the accumulation of sediments increased more than 300% reaching 68.4 mg cm^{-2} yr^{-1} at the core-top sediment strata.

In Sturgeon Lake, in McConnel and Kennedy Bays, an increase of sediment accumulation rate began in the late 1930's (Fig. 6). The general trend of sediment deposition is similar to the accumulation curve in Rice Lake. However, in Kennedy Bay, since ca. 1973 the accumulation profile fluctuates more than at the other sites. This phenomenon was probably caused by the input of sedimentary detritus of marsh origin via the Scugog River.

Organic matter

In Rice Lake the concentration of organic matter was relatively high and ranged between 29.75 - 34.17% of dry matter. The stratigraphy of its concentration showed very small fluctuation (Fig. 7). Two periods of lowest concentration were observed. The first period was represented by the deepest part of the core and the second one by the upper 8 cm of the profile.

In both cores from Sturgeon Lake the concentration of organic matter was very high (Fig. 8) and ranged between 37.39 - 75.39 % in the core from Kennedy Bay, and 35.31 -

83.64 % in the core from McConnel. The stratigraphy of the organic matter showed an increase upwards in the profile. The highest concentration was noticed in the upper part of the core.

Chlorophyll derivatives

In Rice Lake, the accumulation rate of chlorophyll derivatives (CD) ranged from 0.63 to 16.69 SPU dm^{-2} yr^{-1} indicating one general trend - its consistent increase upwards in the profile (Fig. 9). In the lower part of the core (dated ca. 1908 - 1932) the accumulation rate was low, ranging from 0.63 to 1.20 SPU dm^{-2} yr^{-1}. The most significant increase was observed between ca. 1968 and 1971. From ca. 1971 on, the accumulation of chlorophyll derivatives decreased and underwent wide fluctuation. The upper part of the core (dated ca. 1983 - 1986) was characterized by successive increases in CD accumulation rate. The deposition of CD in that period was 2 times higher than those measured in the late 1960's.

In Sturgeon Lake, the general trend of the chlorophyll derivatives stratigraphy was similar to that observed in Rice Lake. The accumulation of CD ranged between 0.61 - 10.96 SPU dm^{-2} yr^{-1} in Kennedy Bay and 0.57 - 18.60 SPU dm^{-2} yr^{-1} near McConnel (Fig. 9). The most significant increase was noticed in the mid 1970's. From that time to 1986 the deposition of CD increased almost 4 times.

Oscillaxanthin and myxoxanthopyll

In the profile from Rice Lake, the accumulation rate of myxoxanthophyll fluctuated widely and ranged from 8.85 to 19.24 ug dm^{-2} yr^{-1}. The highest accumulation was observed in ca. 1970 - 1972 (Fig. 10), while the lowest was noticed in the oldest part of the core ca. 1908 - 1932. Between ca. 1962 - 1986 several narrow peaks were noticed.

The accumulation of oscillaxanthin followed very closely the chlorophyll derivatives profile (Fig. 9). The lowest values of oscillaxanthin deposition were observed in the oldest part of the profile (Fig. 11), while the maximum accumulation (307.63 ug dm^{-2} yr^{-1}) was noticed in the upper part of the core (dated ca. 1983 - 1986). In surface sediments, the deposition of oscillaxanthin was 16 times higher than in the deepest parts of the profile (dated ca. 1908 -1932).

In Sturgeon Lake, the accumulation of myxoxanthophyll, was much lower than that observed in Rice Lake (Fig. 10). In the core from Kennedy Bay, the accumulation rate ranged between 3.43 and 60.50 ug dm^{-2} yr^{-1} while near McConnel the deposition ranged from 5.07 to 192.49 ug dm^{-2} yr^{-1}. The significant increase of myxoxanthophyll was noticed in the mid 1930's. From that time the accumulation rate gradually increased upwards in the cores, fluctuating widely between ca. 1966 - 1986.

Similar to myxoxanthophyll, the accumulation rate of oscillaxanthin was much lower than that observed in Rice Lake (Fig. 11). The value of oscillaxanthin ranged between 4.08 and 45.58 ug dm^{-2} yr^{-1} in the core from Kennedy Bay and from 5.07 to 156.77 ug dm^{-2} yr^{-1} in the core near McConnel.

In Sturgeon and Rice Lakes the stratigraphy of oscillaxanthin and myxoxanthophyll deposition followed the chlorophyll derivatives stratigraphy.

DISCUSSION

The CD : TC ratio as an index of fossil pigments preservation

The amount of fossil pigment deposited in sediments is correlated with differential degradation of pigments during sedimentation as well as their preservation in sediments. This phenomenon was described by Fogg & Belcher (1961) and Belcher & Fogg (1964). The authors indicate that the preservation of carotenoids is far more sensitive to redox conditions than for chlorophylls. The chemical basis for this is that enzymatic destruction of carotenoids depends on the presence of oxygen, whereas further breakdown of chlorophyll degradation products, mainly pheophorbides is

less effected by oxygen. In dimictic lakes, the availability of oxygen in surface sediments can be an inverse function of increasing eutrophy. This could simply indicate that the ratio of CD : TC (chlorophyll derivatives to total carotenoids) should be much lower in eutrophic, dimictic lakes than in oligotrophic or polymictic lakes with a high oxygen concentration in bottom waters.

In Rice and Sturgeon Lakes, the stratigraphy of the CD : TC ratio suggests a degradation of carotenoids in the upper part of the core (Fig. 12, 13). The ratio positively correlates with increasing concentration of chlorophyll derivatives. This could be a result of aerobic conditions of the bottom waters which caused carotenoids to decompose preferentially. However, it is rather unlikely that during the post-settlement period an improvement in bottom water oxygen conditions could have taken place. Usually, human disturbance is associated with eutrophication which would enhance better preservation of pigments. The only reasonable explanation for this down-core trend in CD : TC could be that higher values of the CD : TC ratio were due to the higher chlorophyll production per unit biomass and destruction of carotenoids resulted from polymictic conditions in lakes.

The higher CD : TC ratios observed below 28 cm in the Sturgeon Lake cores could indicate either 1) that oxygen concentration at the surface sediment at that time in the

lake's history were higher than in recent years and afforded better preservation of chlorophylls than carotenoids or 2) that chlorophyll production in the early history of the lake was higher under rates of carotenoid degradation that were similar to present day rates. Higher rates of chlorophyll production (per unit organic matter) may be caused by an increase in the importance of macrophytes relative to algae.

The observation by Rybak (1985) suggests that variations in the CD : TC values may also be caused by relative changes between phytoplankton and macrophyte production. Aquatic plants contribute a higher portion of chlorophylls than carotenoids to lake sediments and as a result higher values of the CD : TC ratio are observed. This can indicate that relatively more macrophyte growth in Rice and Sturgeon Lakes was a feature of the recent period of time. Both lakes are shallow, with much of the area less than 4 m deep and have a rich organic substrate. As a result, prolific stands of aquatic plants are observed in these lakes (moreso in Rice Lake). It seems also, that in recent times the contribution of macrophyte to total sediment deposition is much higher in Sturgeon than in Rice Lake because in Sturgeon Lake, the surface sediments are much more organic than in Rice Lake and the CD : TC values are also higher than in Rice Lake.

This seems contradictory given that lakewide distribution and biomass of macrophytes in Rice Lake are greater than in Sturgeon Lake (Ontario Ministry of the

Environment, 1976; unpublished data). However, the input of organic detritus of marsh origin to Sturgeon Lake (via the Scugog River) may be very significant as a source of organic matter for sedimentation in Sturgeon Lake.

Chlorophyll derivatives as an indicator of trophic status and lake primary production

The deposition of chlorophyll derivatives (CD) in lake sediments is often interpreted as indicative of lake productivity and trophic status (Vallentyne, 1955; Gorham, 1960, 1961; Brown, 1969; Sanger & Crowl, 1979; Rybak & Rybak, 1985 a, b; Rybak, 1987 a; Rybak & Dickman, 1987; Rybak et al. 1987). There are also many studies which show that there is a significant positive correlation of surface sediment CD content and primary production in lakes (Gorham et al. 1974; Adams et al. 1978; Guilizzoni et al. 1983).

In Rice and Sturgeon Lakes the general trend of increasing deposition of chlorophylls is related to trophic changes in the lakes. The most significant increase of CD deposition started ca. 1968 - 1971 in Rice Lake and in the mid 1970's in Sturgeon Lake.

As indicated before, there was also a high contribution of aquatic plants in sedimentary organic matter. Rybak (1985, 1987 b) noticed that in such sediments the deposition

of chlorophylls is much lower due to lower production of chlorophylls per gram organic matter by macrophytes than by algae. This shows that prolific weed growth could directly change the deposition of chlorophylls in sediments and the primary production in the lakes would be much higher than those with lower CD concentration.

Stratigraphy of oscillaxanthin and myxoxanthophyll as an index of blue-green algal development

Significant changes of oscillaxanthin and myxoxanthophyll concentration in cores from Sturgeon and Rice Lakes should be viewed critically, because of the great sensitivity of those pigments to preservation conditions. As noticed by Swain (1985) changes in concentration of those pigments by a factor 20 in response to changes in hypolimnetic oxygen conditions are not inconsistent.

The ratio of maximum to minimum concentration values is much higher for blue-green algal pigments (Fig. 14, 15) than for chlorophyll and total carotenoids (Fig. 16, 17). This suggests that oscillaxanthin and myxoxanthophyll were more susceptible to degradation than either chlorophyll or carotenoids.

It seems even more interesting that in Rice Lake and in Sturgeon Lake near McConnel, oscillaxanthin showed successive increases upwards in the core. The most drastic

shift in oscillaxanthin deposition was observed in recent sediments. In this case, there are two pieces of evidence which indicate that the increase in blue-green algal pigments in Rice Lake resulted largely from the increase of production, rather than enhanced preservation. Firstly, the increases of oscillaxanthin deposition were correlated with higher accumulation rate of chlorophyll derivatives. Secondly, there is an earlier period (36-30 cm; dated ca. 1908 - 1936) of equally good preservation (inferred from lower CD : TC ratio) during which oscillaxanthin changed little. Because oscillaxanthin did not increase during that period the gradual increase initiated in the mid 1930's must have resulted from the increase in production of this pigment by Oscillatoria. In Rice and Sturgeon Lakes the sediment myxoxanthophyll showed the same tendency and followed very closely the deposition of chlorophyll derivatives.

Oscillaxanthin and myxoxanthophyll are relatively sensitive to preservation conditions and they degrade at similar rate (Swain, 1985). However, the same author established also that oscillaxanthin may degrade slightly faster in some cases than myxoxanthophyll. The OSC/MYX ratio can be a measure of the relative production of these pigments, where higher values indicate that Oscillatoria plays an important role in blue-green algal flora.

The core from Rice Lake suggests that a significant increase of Oscillatoria in relation to other blue-green algae occurred in the recent history of the lake (upper 3 cm). At the same time other blue-green algae increased too (myxoxanthophyll). As a result, the three surface layers showed a decrease in the OSC/MYX ratio between 3 cm and 1 cm (Fig. 12). However, it appears that Oscillatoria was still represented in relatively high abundance. That however, does not mean that the lake was necessarily dominated by Oscillatoria.

In Sturgeon Lake the concentration of both pigments was probably controlled more by the preservation conditions and fluctuated much more than in Rice Lake. In the core from Kennedy Bay the values of OSC : MYX ranged from 0.48 to 2.86 while ranging between 0.6 to 5.1 in the core from McConnel (Fig. 13). Consequently, it is impossible to use the ratio as an indicator of changes in the blue-green algal populations.

Our present knowledge regarding the concentration of blue-green pigments in sediments of eutrophic versus oligotrophic lakes is still inadequate. Eutrophic lakes exhibit various patterns - some with high and some with low concentrations of oscillaxanthin. Swain (1985) noticed that the blue-green algal flora of some oligotrophic lakes may be more likely dominated by Oscillatoria than in eutrophic lakes. However, there are several well known Ocillatoria

species which prefer eutrophic or even saprotrophic waters. Zullig (1961), Brown and Colman (1963) and Gorham and Sanger (1976) recorded the dramatic increases of oscillaxanthin and myxoxanthophyll in sediments as a result of development of blue-green algal populations in response to cultural eutrophication. This assumption seems adequate for Rice and Sturgeon Lake conditions. The mass development of blue-green algae associated with high abundance of Oscillatoria was probably correlated with the escalation of the eutrophication process in the lakes. Oscillatoria redekei has been more important in the summer plankton of Rice Lake than in Sturgeon Lake in recent years (K. Nicholls, personal comm.) and supports the sediment pigment findings.

SUMMARY AND CONCLUSIONS

1. In Rice and and Sturgeon Lakes, sediment oscillaxanthin showed successive increase upwards in the cores. The most important increase was observed in recent sediments. The mass development of blue-green algae, associated with high abundance of Oscillatoria is a symptom of the eutrophic status of the lakes.
2. In Rice and Sturgeon Lakes a general trend of increasing deposition of chlorophylls is indicative of trophic changes in the lakes. The most significant increase of

chlorophyll accumulation was observed in the youngest part of the cores. The stratigraphy of chlorophyll derivatives concentration, organic matter deposition as well as CD : TC ratio suggests that the prolification of macrophytes was an important component of the eutrophication process. 3. In recent times the contribution of macrophytes to total sediment deposition was much higher in Sturgeon than in Rice Lake. This phenomenon was probably caused by the input of organic detritus of marsh origin to Sturgeon Lake via the Scugog River.

4. The stratigraphy of the CD : TC ratio suggests a high degradation of carotenoids in the upper part of cores from Rice and Sturgeon Lakes, owing to unfavourable conditions for preservation (oxygenated surface sediments ?). Changes in the CD : TC ratio were also related to changes in relative production rates of chlorophyll and carotenoids (i.e. changes between phytoplankton and macrophyte production).

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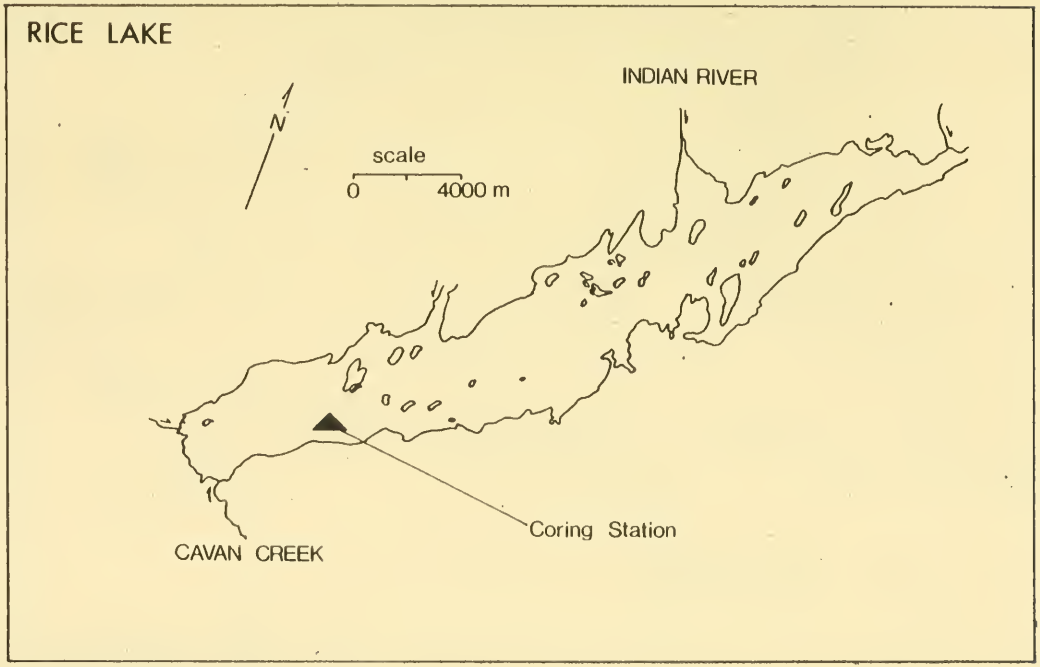

Fig. 1. Map showing the location of coring station in Rice Lake

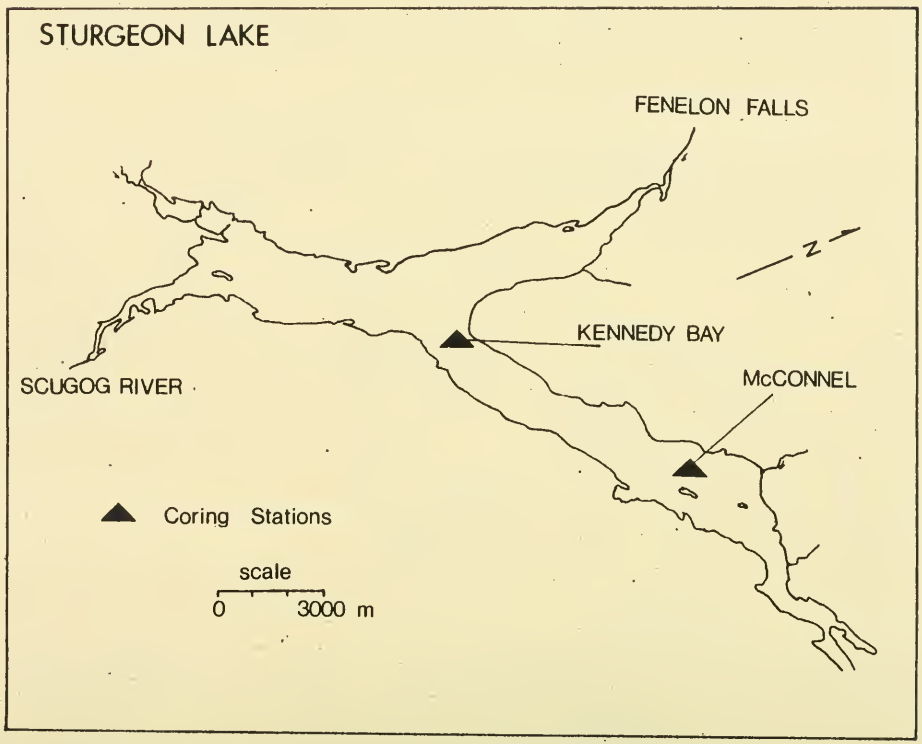

Fig. 2. Map showing the location of coring station in Sturgeon Lake

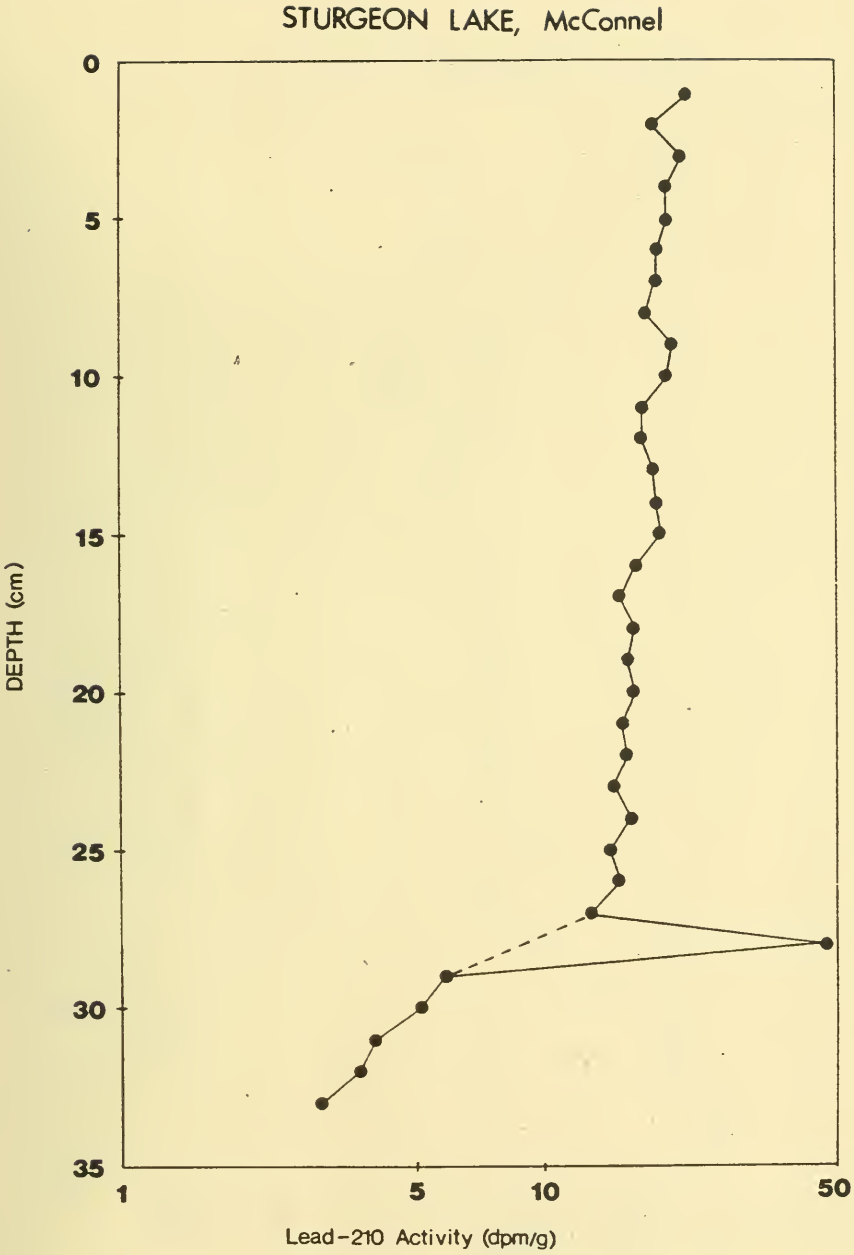

Fig. 3. Stratigraphy of lead-210 activity in the sediment core from Sturgeon Lake, near McConnel. The peak at 28 cm is belived to be erroneous.

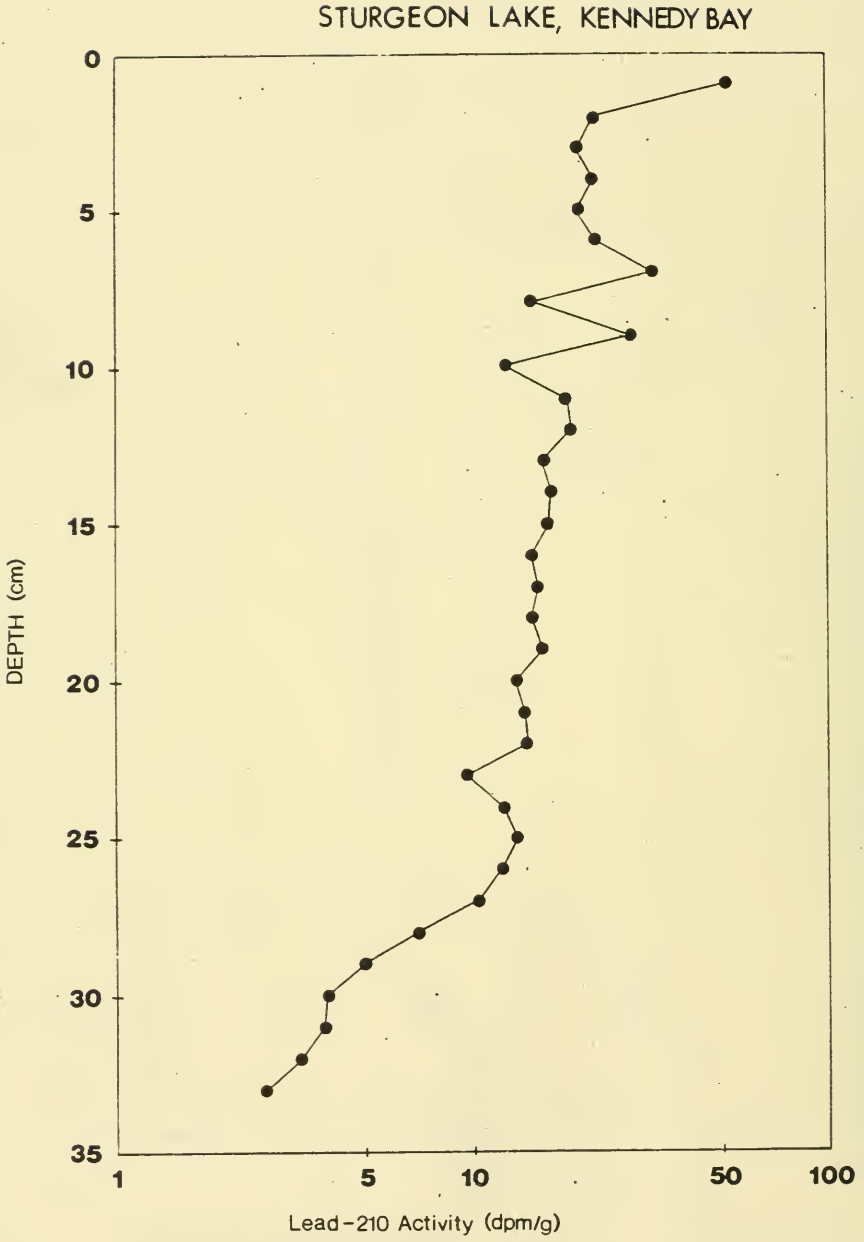

Fig. 4. Stratigraphy of lead-210 activity in the sediment core from Sturgeon Lake, Kennedy Bay

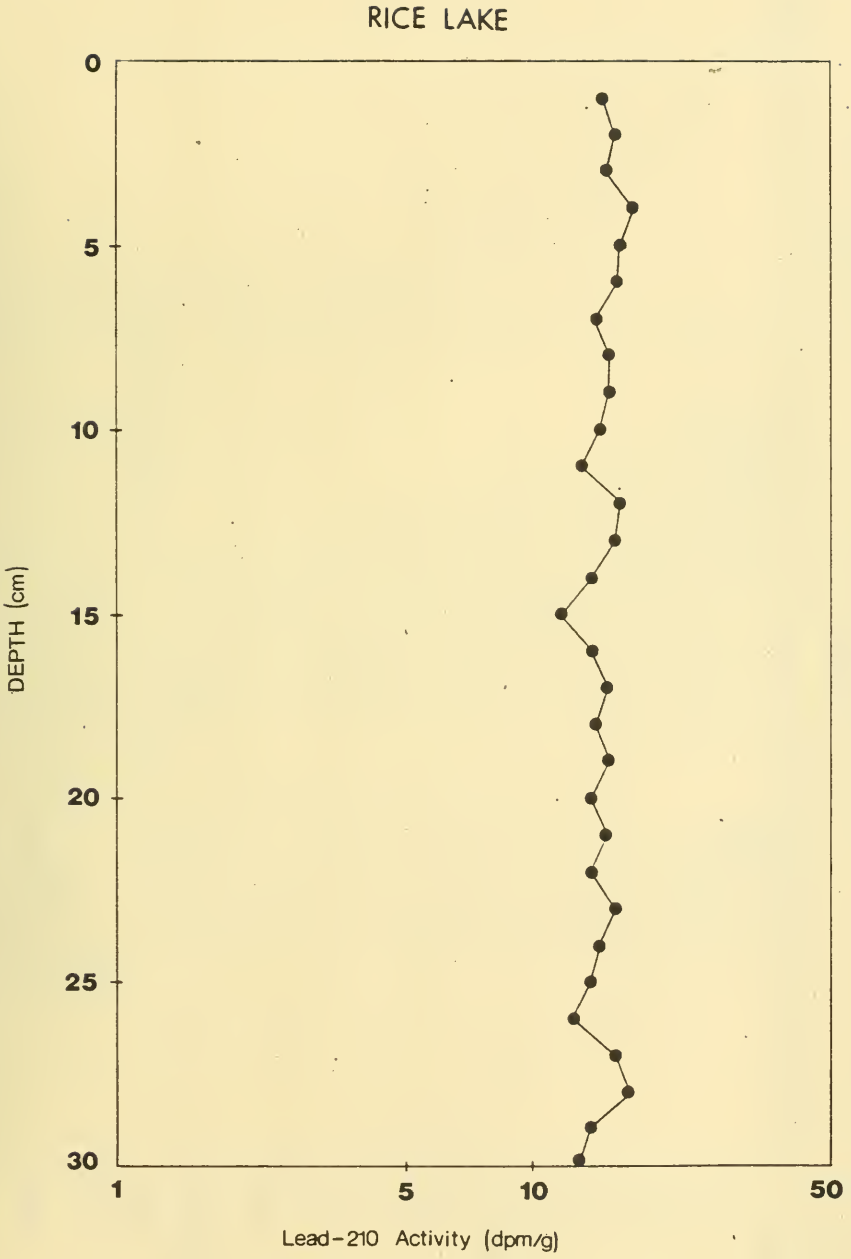

Fig. 5. Stratigraphy of lead-210 activity in the sediment core from Rice Lake

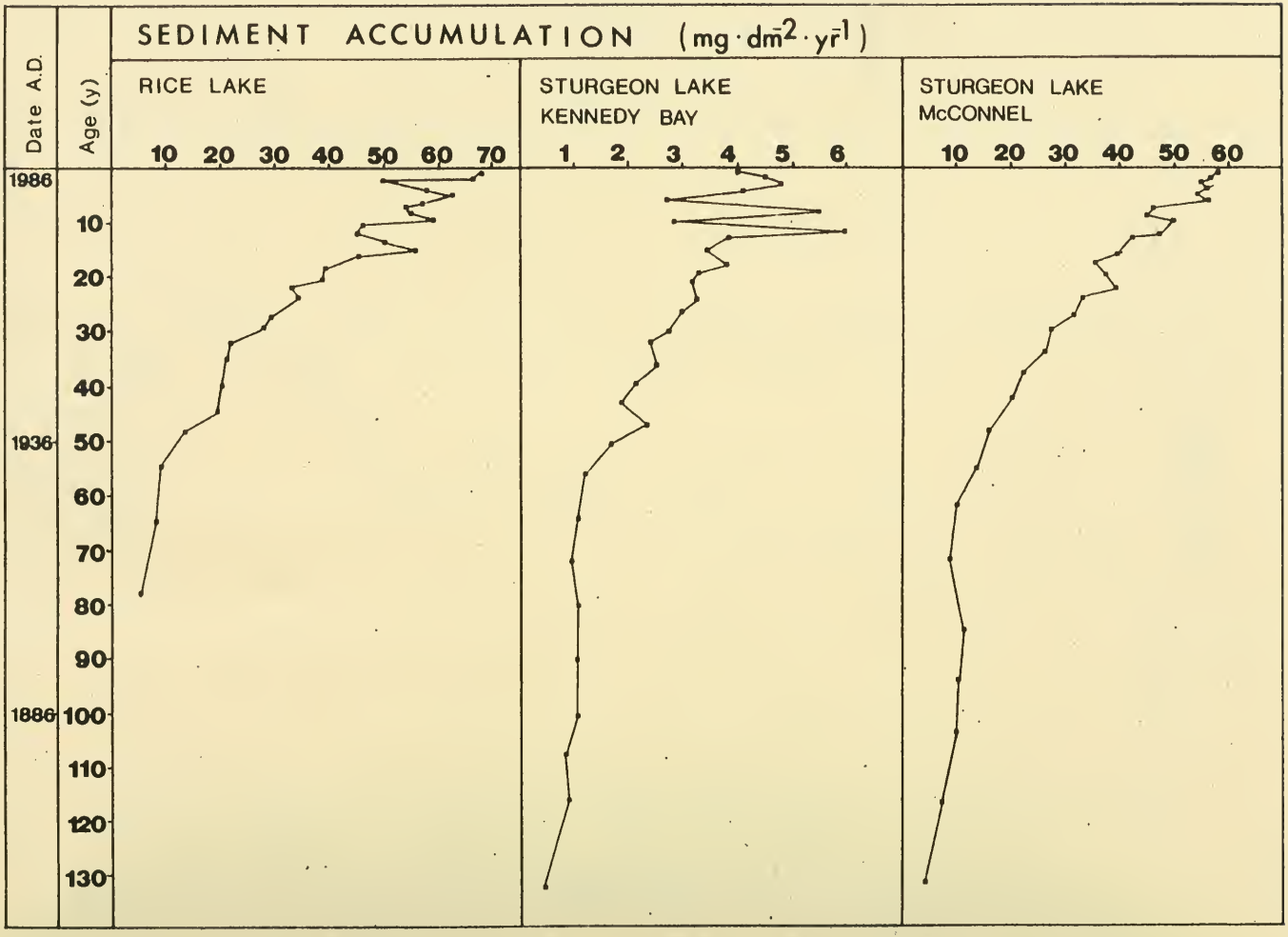

Fig. 6. Sediment accumulation rate in the Rice and Sturgeon Lake cores as determined by lead-210.

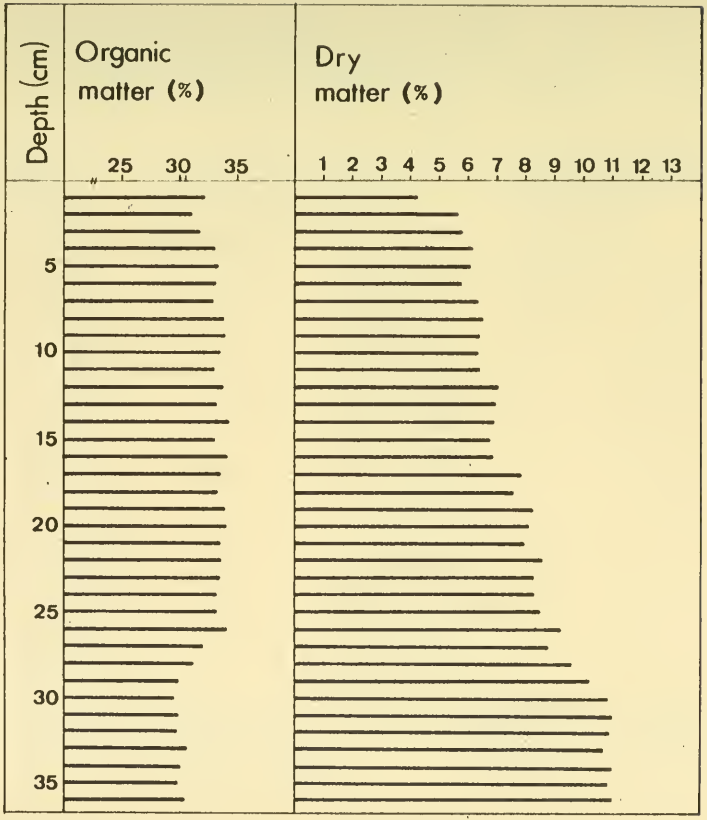

Fig. 7. Organic matter as per cent of dry weight and dry matter in the core from Rice Lake

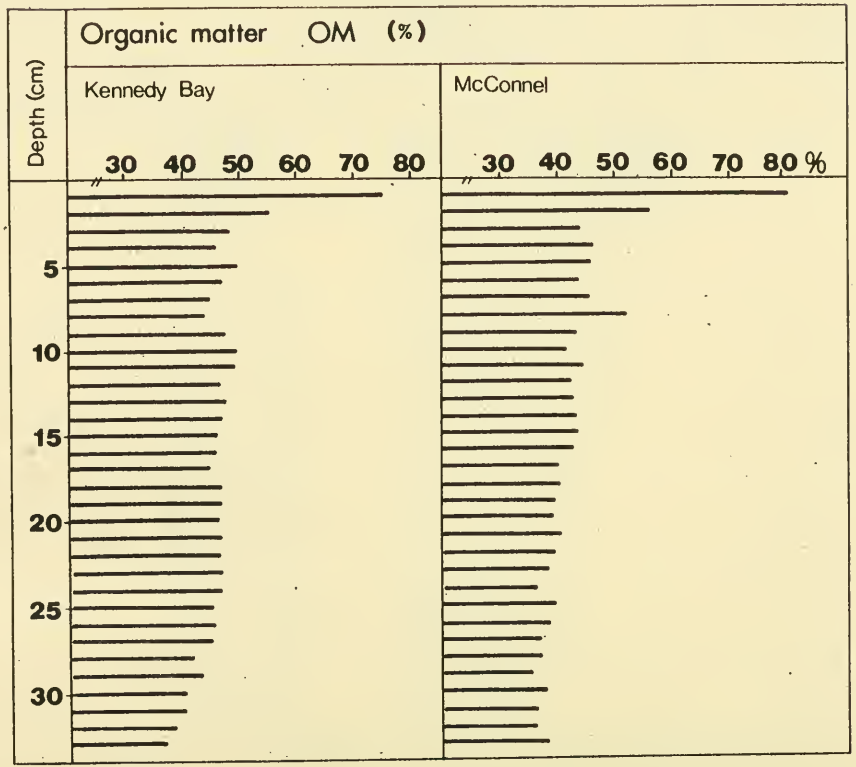

Fig. 8. Organic matter as per cent of dry matter weight in two cores from Sturgeon Lake

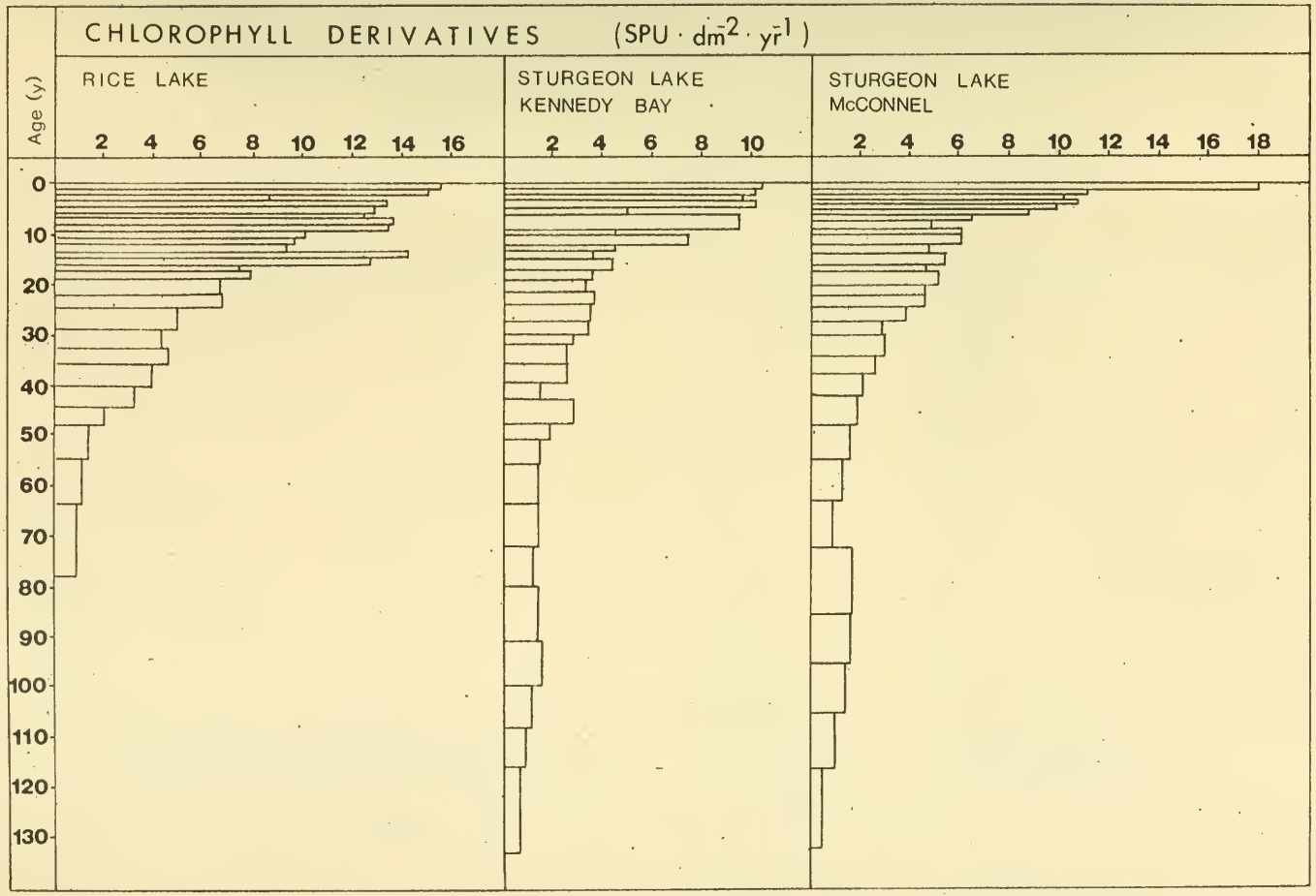
CHLOROPHYLL DERIVATIVES (SPU · dm⁻² · yr⁻¹)
Age (y)
RICE LAKE
STURGEON LAKE
KENNEDY BAY
STURGEON LAKE
McCONNEL
2 4 6 8 10 12 14 16
2 4 6 8 10
2 4 6 8 10 12 14 16 18
0 10 20 30 40 50 60 70 80 90 100 110 120 130

Fig. 9. Chlorophyll derivatives accumulation rate in the cores from Rice and Sturgeon Lakes

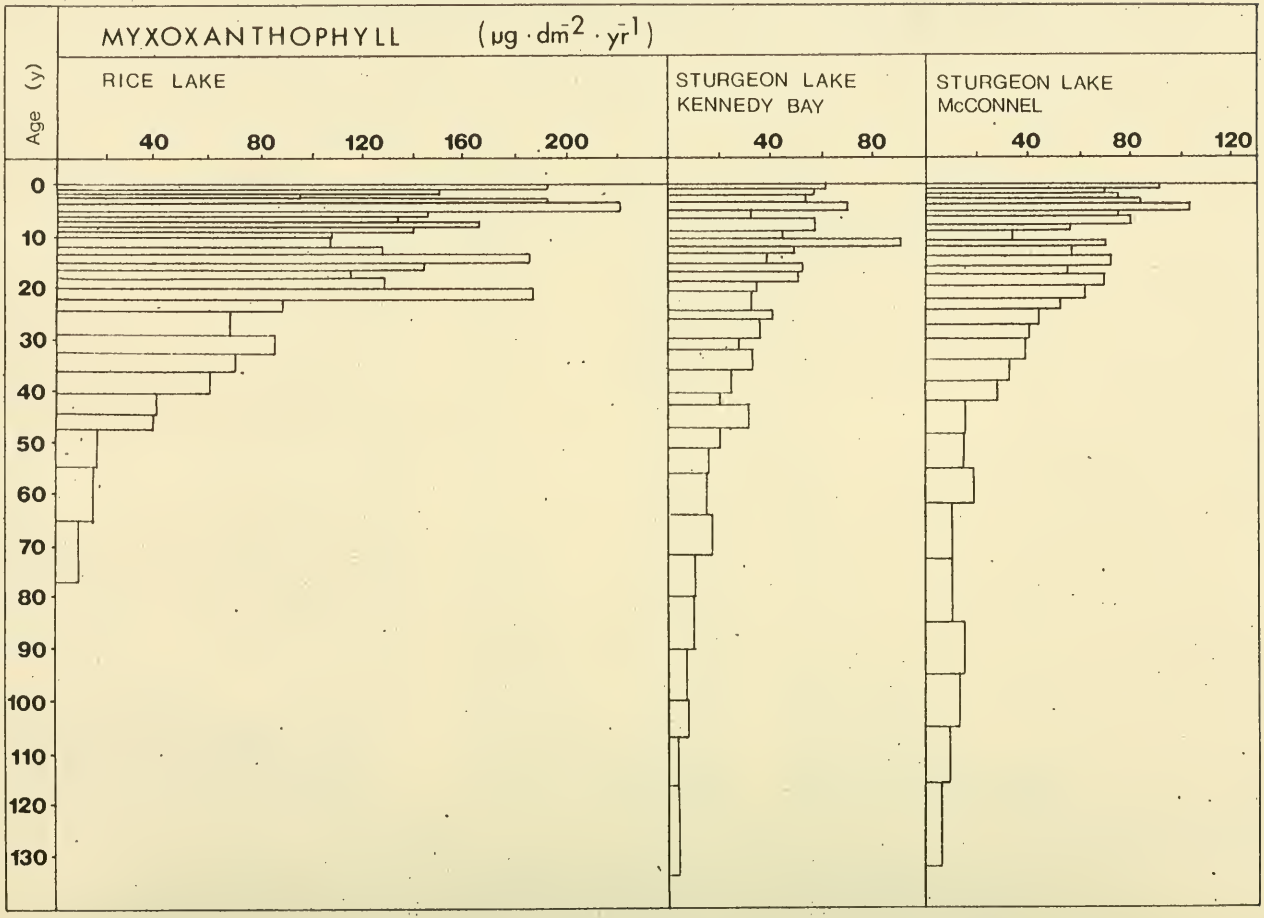

Fig. 10. Myxoxanthophyll accumulation rate in the cores from Rice and Sturgeon Lakes

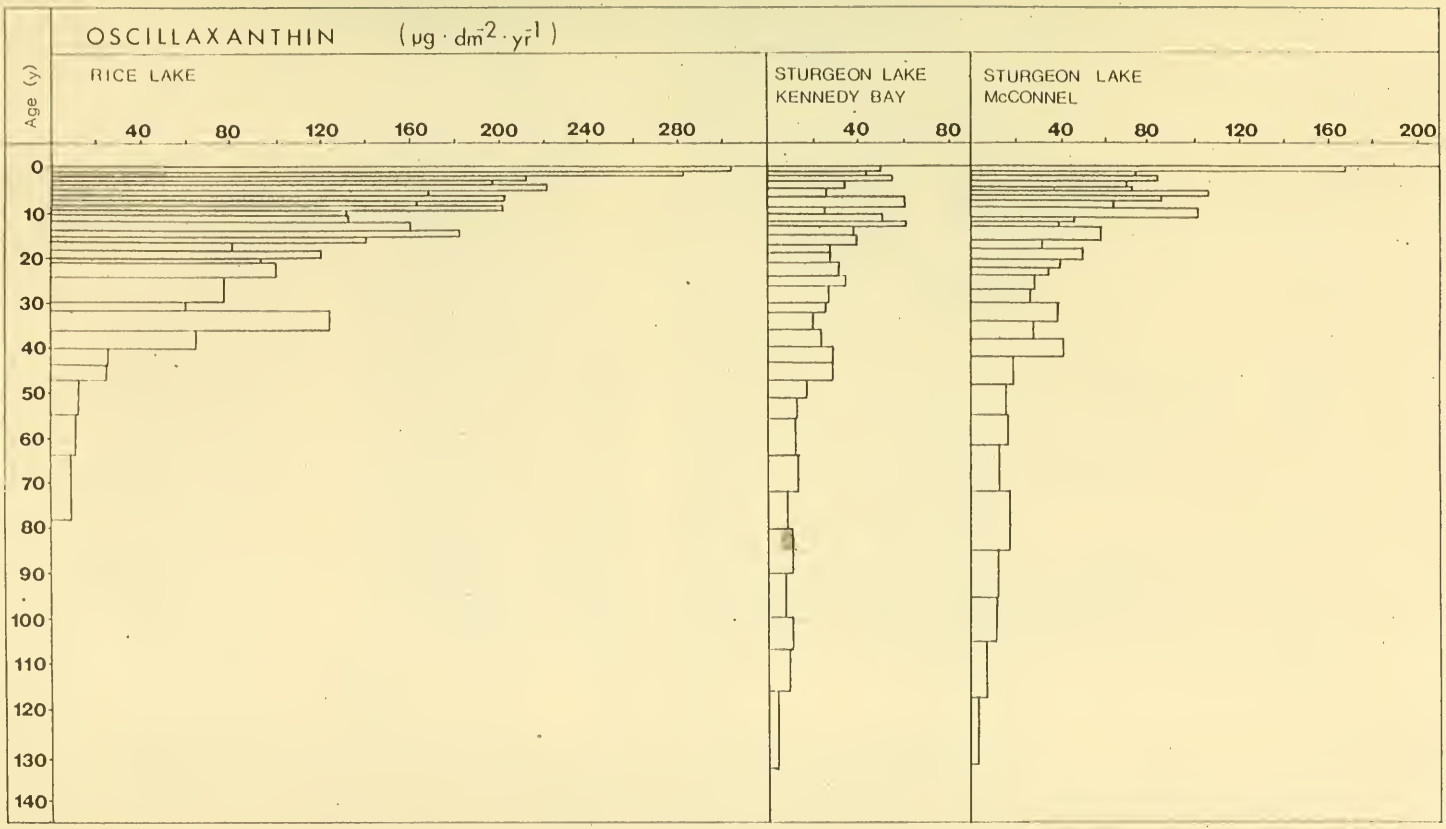

Fig. 11. Oscillaxanthin accumulation rate in the cores from Rice and Sturgeon Lakes

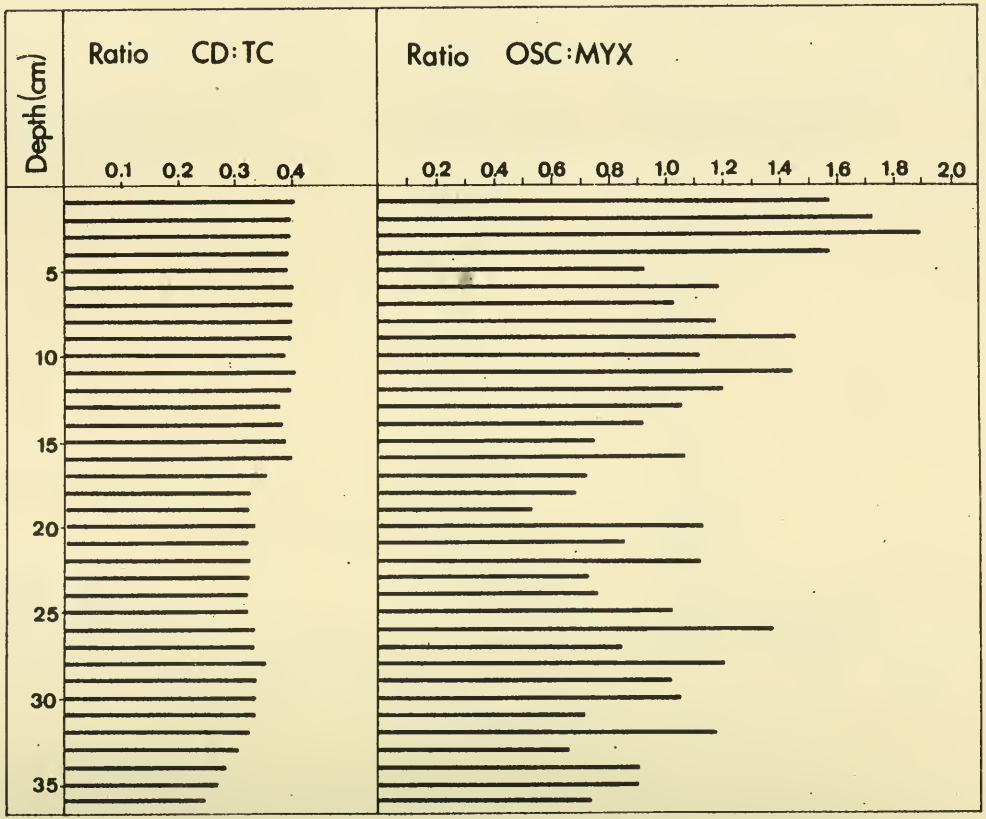

Fig. 12. Profiles of the ratios chlorophyll derivatives to total carotenoids (CD:TC) and oscillaxanthin to myxoxanthophyll (OSC:MYX) in Rice Lake

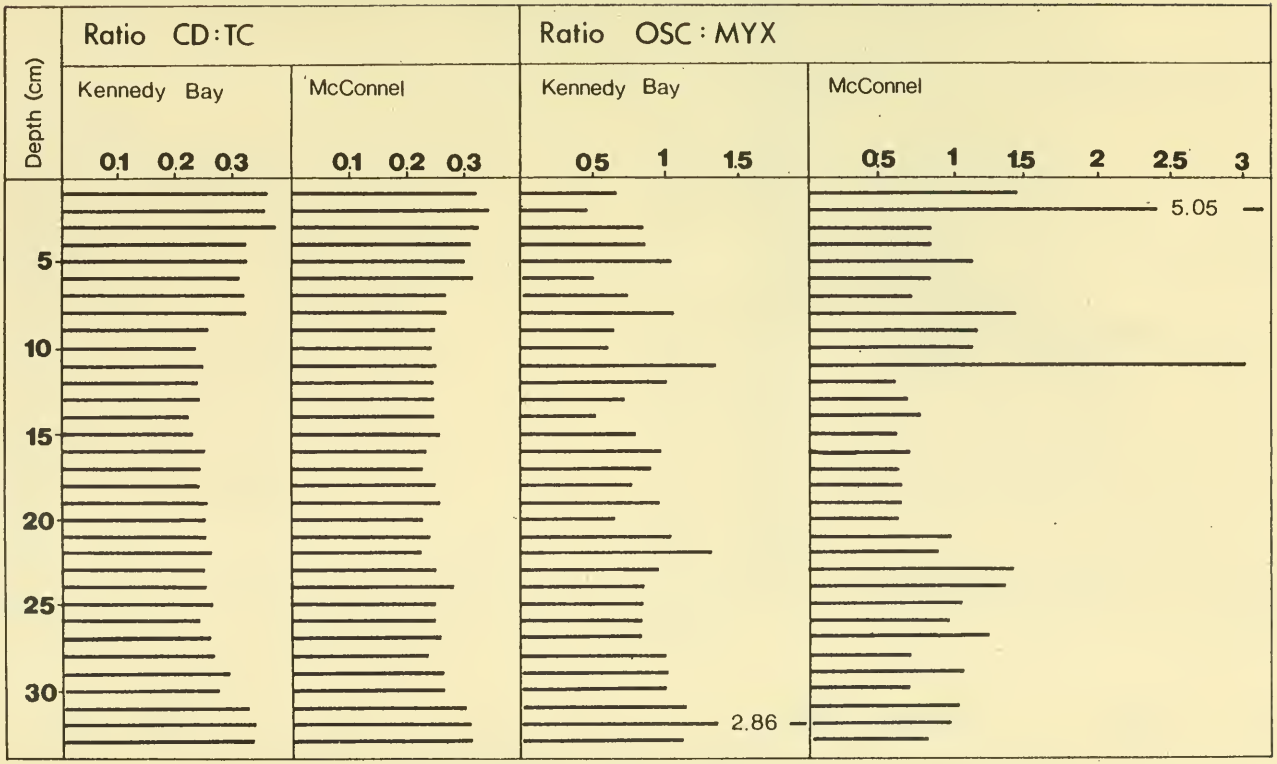

Fig. 13. Profiles of the ratios chlorophyll derivatives to total carotenoids (CD:TC) and oscillaxanthin to myxoxanthophyll (OSC:MYX) in two cores from Sturgeon Lake.

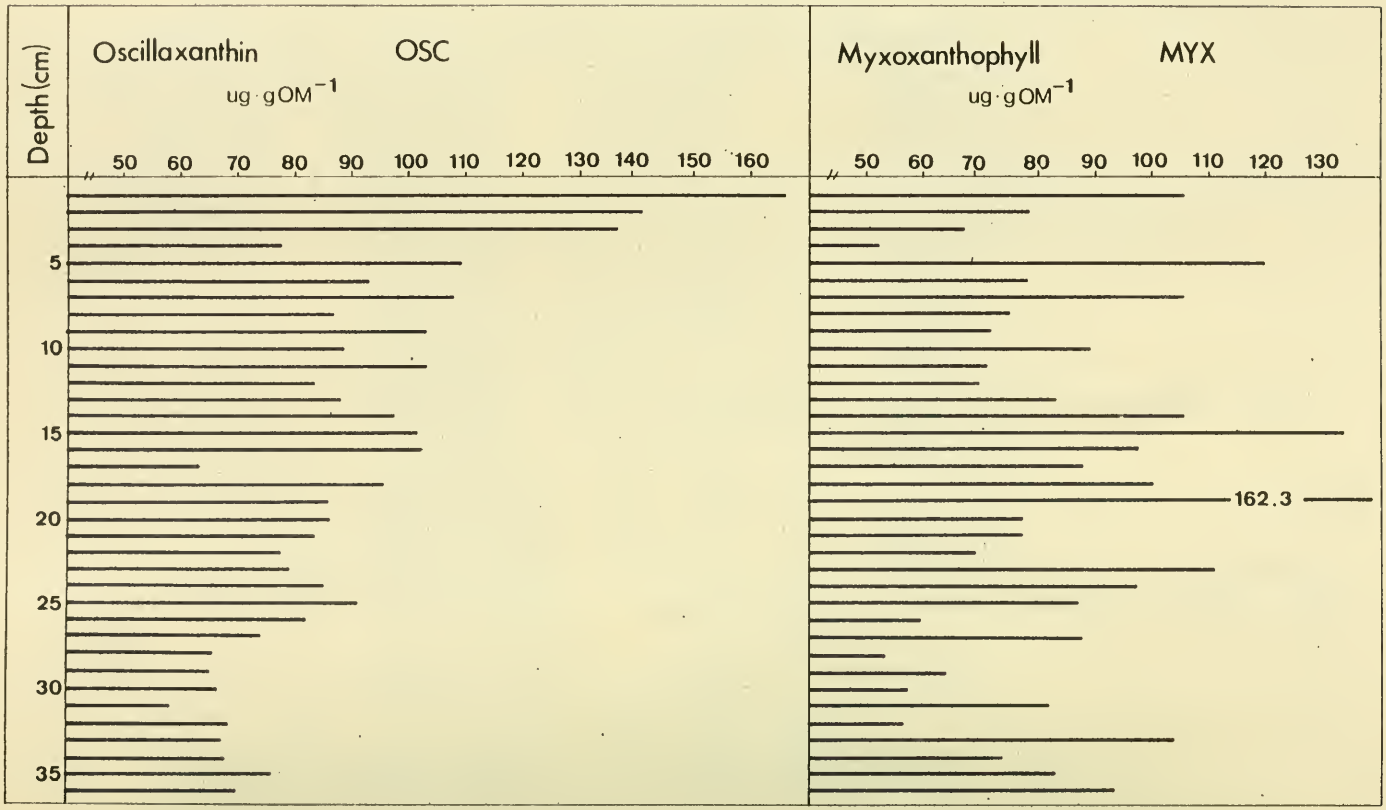

Fig. 14. Oscillaxanthin (OSC) and myxoxanthophyll (MYX) stratigraphy in the core from Rice Lake, calculated as concentration per gram organic matter

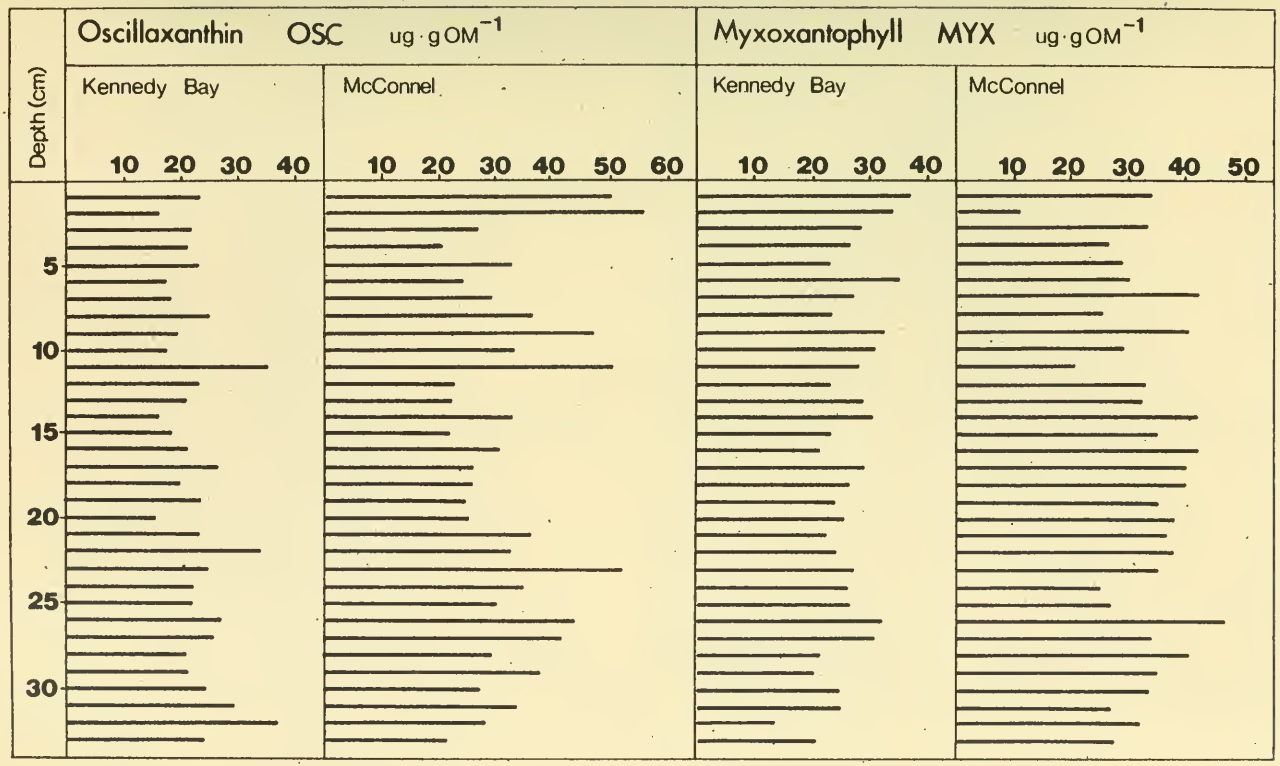

Fig. 15. Oscillaxanthin (OSC) and Myxoxanthophyll (MYX) stratigraphy in two cores from Sturgeon Lake, calculated as concentration per gram organic matter

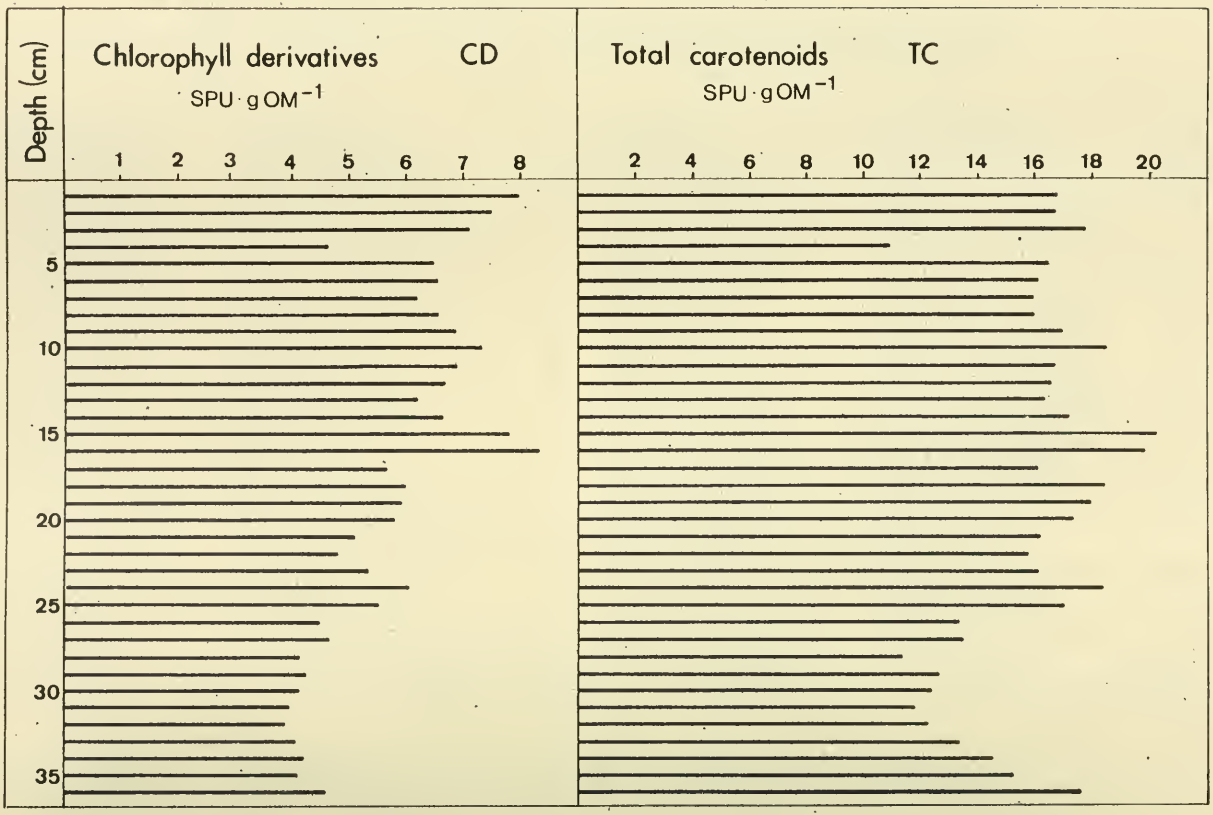

Fig. 16. Chlorophyll derivatives (CD) and total carotenoids (TC) stratigraphy in the core from Rice Lake in standard pigment units (SPU) per gram organic matter

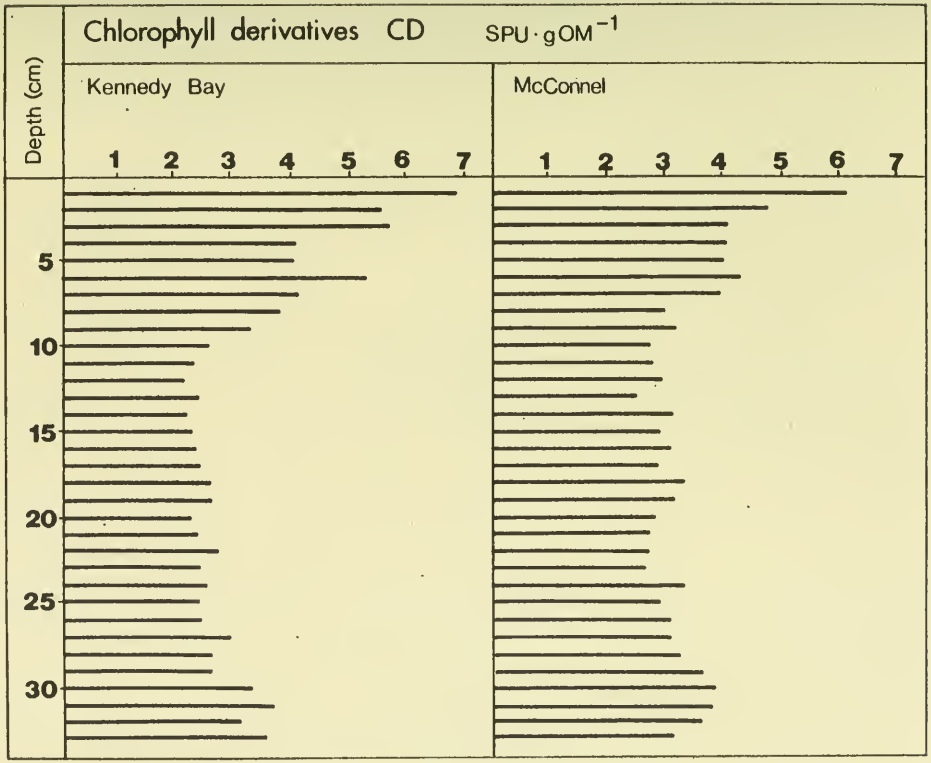

Fig. 17. Chlorophyll derivatives (CD) stratigraphy in two cores from Sturgeon Lake in standard pigment units (SPU) per gram organic matter